Technology to Sort Lumber by Color and Grain for Furniture Parts

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Abstract

This paper describes an automatic color and grain sorting system for wood edge-glued panel parts. The color sorting system simultaneously examines both faces of a panel part and then determines which face has the "best" color, and sorts the part into one of a number of color classes at plant production speeds. In-plant test results show that the system generated over 91 percent acceptable panels from automatically sorted red oak panel parts, which exceeded target plant production goals. The technology is also capable of grain sorting panel parts. While sorting parts by grain appears promising in laboratory testing, the grain sorting performance of the technology has not yet been tested in an actual production environment. The color sorting system is a patented technology and is now commercially available under the name of CESYS by Group Seven Systems.

Introduction

Color and grain sorting of furniture parts is an important manufacturing step where color uniformity has an impact on the value of the final products. Figure 1 illustrates how color uniformity can affect the look of the panel product that is produced. Manual color sorting of parts is very labor intensive and inexact, as different people have different perceptions about color uniformity in hardwood panels. Additionally, color uniformity and consistency of manually sorted panels further decline over a period of time at production speeds.

Because a distinct market preference for color and grain uniformity exists, a number of researchers have proposed and examined systems to better characterize color in wood. These systems, however, have not led directly to commercially available systems that can meet the demands of the wood processing industry In creating a sorting system that will work in the industry, it must meet the following requirements:

1. able to accurately and consistently separate parts into appropriate color and grain pattern classes,

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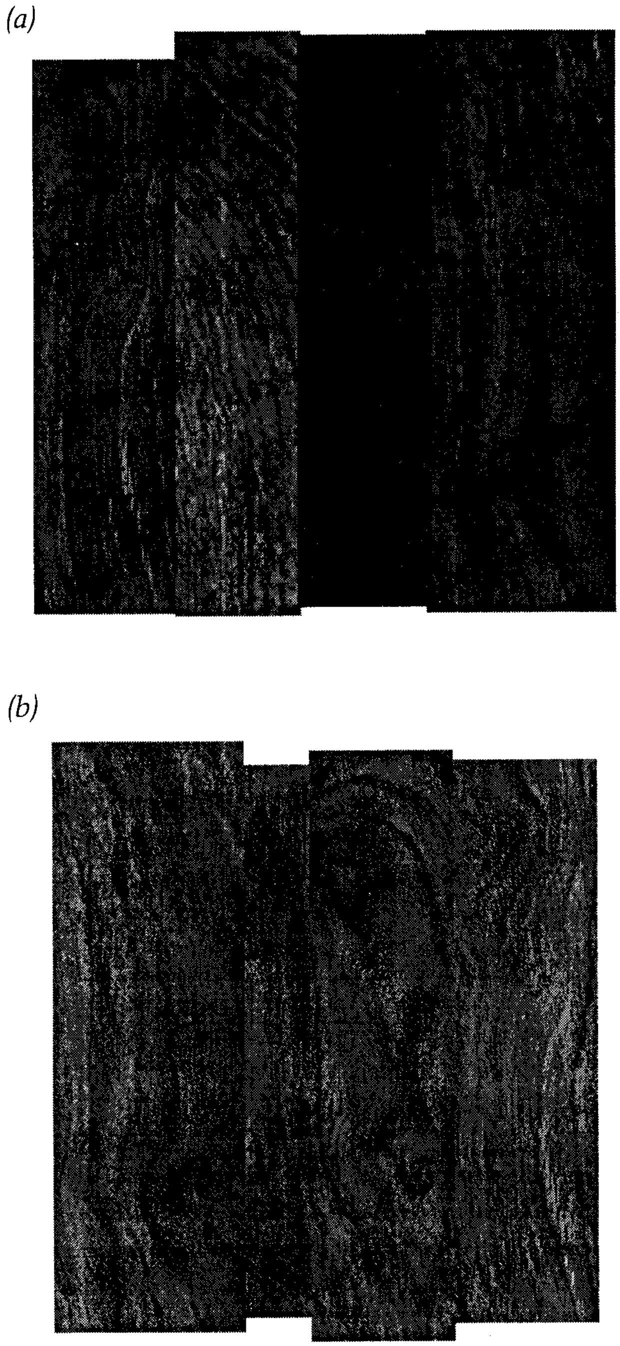


Figure 1. —*Red oak panel color (brightness) variation for (a) improperly sorted panel parts and (b) properly sorted panel parts.*

2. able to keep up with the production requirements of the plant, and
3. be easy to operate by plant production personnel.

An automatic color and grain sorting system has been developed which now meets all of these requirements. This paper briefly describes the sorting system alongwith some initial in-plant testing results.

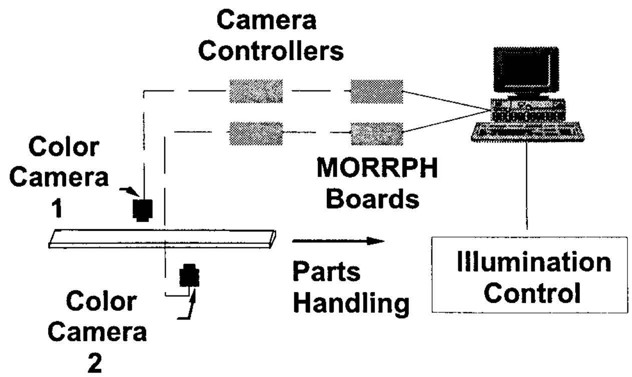


Figure 2. —*Overall system hardware design for the color sorting system.*

System Hardware and Software

For the color sorting system to be useful in an actual application, the system was designed to have a throughput of at least 2 ft. (61 cm) per second. The parts inspected by the system must be able to scan widths from 1 in. (25 mm) up to 7.5 in. (190 mm) and handle random lengths. To accurately gage the color of a scanned part, a high-resolution color image of at least 32 points per in. (1.3 points per mm) must be attained. Implementing an accurate color sorting algorithm on such high resolution color image data along with other necessary image processing requirements such as color shading compensation and background extraction cannot easily be achieved to meet the real-time throughput requirements unless special purpose image processing and computing hardware are used.

Figure 2 shows the overall system hardware design used to perform real-time color sorting operations. The system uses color line scan cameras to image the parts, one camera for each part face. The digital data coming out of each color camera controller is input to a special purpose image processing board that was designed and built at Virginia Tech. This board is called the Modular Reprogrammable Real-time Processing Hardware, or MORRPH (2,3). The MORRPH boards processes the input camera signal and output the color measurement histograms (the relative frequency of colors) from which parts are sorted into appropriate color classes. Without the MORRPH boards, real-time processing would be difficult to achieve using a standard computer system. Tungsten

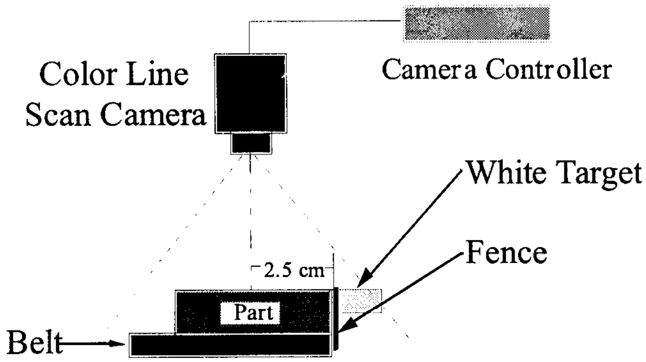


Figure 3. *—Color imaging geometry.*

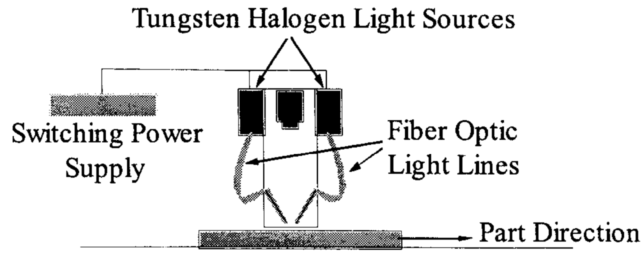


Figure 4. *—Illumination system.*

halogen light sources are used to provide a uniform and consistent illumination source for the system. Consistent illumination is critical to the performance of the color sorting system. Hence, the system is designed to monitor the illumination levels and control them to within certain defined tolerances in real-time.

Each color camera is positioned so that its optical axis is perpendicular to the part face it is imaging (Fig. 3). The parts run through the system on an edge driven by a belt that touches the part face. The optical axis is located 1 in. (2.5 cm.) from this belt. Using this imaging geometry means the system never images a part edge but only a complete part face. The field of view of each camera is such that it not only images a part face but a white target as well. The white target is used to check for variations in lighting.

The illumination system (Fig. 4) for the color sorting system must be as consistent and uniform as possible. The light sources used on the system employ tungsten halogen bulbs. These bulbs are used because the color temperature and light intensity does not vary much across bulb lifetime. Switching power supplies are used to provide power to the bulbs. Each switching power supply has an input that allows the power supply output voltage to vary depending on the input signal. This input allows the illumination control system to adjust the power supply voltage when lighting intensity falls outside a specified tolerance.

The MORRPH boards are the heart of the color sorting system. The MORRPHs perform most of the processing on the collected image data including shading correction on the incoming data, removing background pixels, computing the color measurement vector used to do the sorting, and continuously monitor the output of the light sources. The MORRPH ignores color camera data until it senses a part is entering the field of view at which time it begins computing color measurement data. The MORRPH stops computing color data when it senses the part is leaving the field of view. The MORRPH continuously monitors the lighting, even when a part is not in the field of view. If the lighting changes beyond a defined tolerance, it interrupts the image processing computer so that the computer can signal the light source power supply to increase or decrease the voltage supplied to the bulbs until the defined tolerance is regained.

After the MORRPH senses a part is leaving the field of view of the camera to which it is attached, it immediately sends the color measurement data of the part face its camera has imaged to the image processing computer. This transfer occurs over the ISA bus. The image processing computer performs the pattern recognition algorithm used to classify the color of each part face and perform a best face analysis.

The key to color sorting panel parts is defining a measurement vector that accurately gauges all the natural color variations in wood. A 3-dimensional (3-D) color histogram is used as the measurement vector for the color characteristics of a part face. 3-D color histograms are needed to overcome color separation problems found with simpler methods of color measurement vectors (7). Unfortunately, 3-D color histograms are very large (millions of color components) which can substantially increase the computational complexity needed. To reduce computationally complexity, the techniques used on this color sorting system employ a color mapping algorithm (5) to reduce the size of the measurement vector while preserving the necessary 3-D color information. It was determined experimentally that a 3-D color histogram for red oak panel parts can be accurately represented using 2,000 color elements. Hence, a 256 by 256 by 256 3-D color histogram with over 16 million elements is reduced to a measurement vector that is only 2,000 elements long.

The pattern recognition method used for assigning a part face to a color class is the k-nearest neighbor approach (4). The k-nearest neighbor approach is illustrated in Table 1 for 3 different color classes: 1) red, 2) brown, and 3) white. Each color class is defined with 5 different training samples. A training sample is a reference part used to define the color within a class. The more the training samples used to define a color class are carefully selected, the more adequate representation of the total variability in color that is allowed for parts that is acceptable within a panel. To classify a new part into one of the color classes using the k-nearest neighbor classifier first involves measuring the color difference of the part from the 15 training samples used to define the color classes. The difference measure used is the l_1-norm. The l_1-norm is the sum of the absolute values of the difference between each element in the color measurement vector. Table 1 shows the difference of the new part from each of the training samples. By employing the k-nearest neighbor method with k=3, the 3-nearest neighbors are B2, B3, and R4. More samples from the Brown Class are closer to the part than any other class. Therefore, the part would be classified as Brown.

In general, a part face will be assigned the color class to that which is closest on the k-nearest training samples. Note that if a part face is too far away from any of the training data, it will be placed in an out class. For example, a distance of 0.01 is specified as the distance threshold in which if the threshold were exceeded, then the part would be classified as out. In the example illustrated by Table 1, then, the part would be classified as out since no distance is less than 0.01. The distance threshold used to make this determination is a program input variable. Hence, in those applications where near perfect color sorts are required, this distance can be made small. If, on the other hand, a good deal of color variation is going to be allowed in the panels this distance can be large. For instances where parts are designated as an out class, plant operators can be used to manually determine a part classification.

Once a color class has been assigned, the computer performs a best face analysis. If the color of each face is of equal priority, then the best face is assigned to that which is closest to the training samples. If the color of each face is of different priority, then the best face is assigned to that which is of the highest priority.

Table l. —*Color difference (l_1-norm) of a part from training samples used to define color classes. The 3-nearest neighbors are bold.*

Training samples	l_1-norm
Red class:	
Sample Rl	0.025
Sample R2	0.021
Sample R3	0.031
SampleR4	0.017
Sample R5	0.022
Brown class:	
Sample Bl	0.018
SampleB2	0.015
SampleB3	0.013
Sample B4	0.020
Sample B5	0.021
White class:	
Sample W1	0.043
Sample W2	0.053
Sample W3	0.049
Sample W4	0.055
Sample W5	0.048

The color sorting software also performs all the processing needed to handle features that may be allowed in panel parts such as small knots and mineral streaks. While these features may be allowable on a part face, they can alter or bias the color data collected such that the part can be mis-classified into a different color class. The software has provision to segment out these features, determine if they are within acceptable limits, and exclude feature regions from the color measurement vector.

The above color-sorting algorithm has also been adapted to perform wood grain sorting. Grain sorting requires only black and white images. The system converts a collected color image into a black and white image by averaging the red, green, and blue color channels. With the black and white image, various edge detectors are applied to create gradient images (Fig. 5). For example, vertical and horizontal edge templates are applied to a collected image (Fig. 5a) to create vertical (Fig 5b) and horizontal (Fig. 5c)

(a) (b) (c)

Figure 5. —*Black and white image of a wood grain sample before processing (a) and after applying vertical (b) and horizontal (c) edge templates. White indicates the amount of grain aligned in the vertical direction (b) and the horizontal direction (c) for the sample.*

gradient images. Histograms are created for each gradient image. By comparing these histograms to a set of training samples for desired grain characteristics, the image is assigned to a grain class that is closest on the k-nearest training samples.

Using the above color and grain sorting methods requires that the lighting conditions remain reasonably uniform over time. Hence, there is a need for continually monitoring lighting variations so that these variations can be minimized. It also requires that the lighting and the sensitivity of the CCD imaging elements be perfectly uniform across the field of view. One can never physically achieve absolute uniformity, but a shading correction algorithm (6) can be used to reduce the effects of inevitable variations.

The software system provides for 3 modes of operation:

1. real-time operation,
2. system training, and
3. system setup.

Real-time operation involves those functions used in the actual sorting of parts and continually monitoring lighting variations. System training involves

Table 2. —*Color class description and sample size used to define reference color classes.*

Color class description	Sample size
Dark red	25
Red with some green	25
Red with some white	25
Dark brown	25
Medium brown	25
Light brown	25

those functions used in specifying and characterizing different color classes (reference histograms). System training is based on showing the system a number of part faces that span the range of colors management allowed in a given color class. Any number of color classes can be defined. The computational complexity, however, goes up as the number of classes is increased. Also from a manufacturingviewpoint, more classes mean more space for sorting bins and more complicated material handling systems. Finally, system setup involves specifying different parameters, tolerances, and threshold values that an operator can use to control and fine tune the operation of the system. Complete details on the above hardware and software components are disclosed in U.S. Patent 5,761,070 (1).

Testing the System

The accuracy of the color sorting algorithm was evaluated in an actual panel glue-up operation. A set of color samples were selected to define 6 reference color classes for southern red-oak panel parts. Table 2 lists the 6 colors and the number of samples selected to train the color sorting system. The selected samples were chosen by experienced mill operators such that any combination of the 25 parts within a class would result in a clear panel. The 25 samples for each of the 6 classes were then used to train the color sorting system. The end result of the training procedure resulted in 6 reference color histograms that represented each of the color classes. Light uniformity during the time of training was held constant.

After training the system, the performance of the part sorting algorithm was tested. This particular glue-up operation graded edge-glued panels into 3 categories:

1. clear,
2. acceptable, and

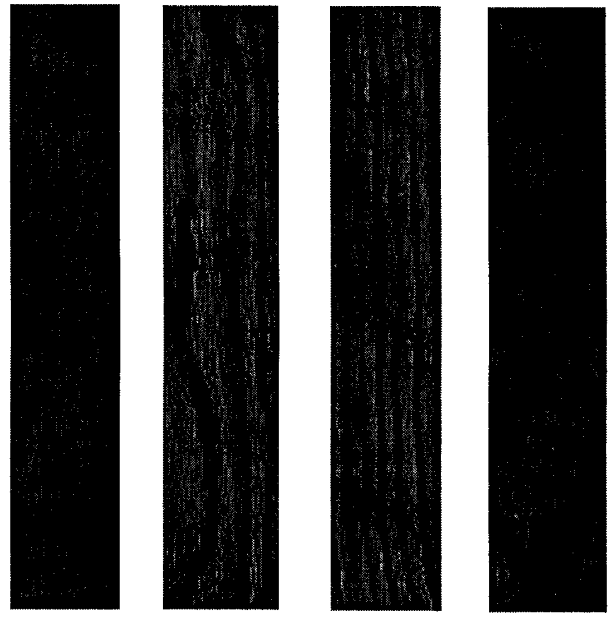
Table 3. —*Percent clear and acceptable panels generated from various pallet loads of red oak panel parts.*

Pallet #	Clear and acceptable panels
	(%)
1	92.0
2	96.9
3	95.0
4	87.1
5	82.0
6	83.0
7	85.0
8	86.0
9	88.0
10	90.0
11	95.0
12	99.1
13	98.0
14	98.0
15	95.0
16	92.0
17	90.0
Average	91.3

3. unacceptable.

Clear panels have approximately the same color across the better face and are the most valuable panels. Acceptable panels have color characteristics that are within acceptable bounds but have some allowable color variation that can be compensated with darker finishes. Unacceptable panels have color characteristics which vary widely across their better face and are typically used to create painted panels.

Table 3 lists the in-plant test results for 17 pallet loads of parts. One load typically contained 900 to 1,000 pieces. Each of these pieces were color sorted with the color sorting system and then glued up into panels required for the production run. The average rate of clear and acceptable panels for the entire experiment was 91.3 percent which was well above those panels resulting from manual color sorting (85%). The highest and lowest rates achieved were 99 and 82 percent, respectively. The lowest rates in the study were later attributed to incorrectly calibrated light levels, dust, and parts that had significantly different color variations that were not represented by any of the 6 color classes used to train the system. Overall, these results indicate that the system is capable of creating high-quality edge-glued panels. However, proper color class training and maintenance of uniform lighting were found to be extremely critical for accurate results. Proper training requires a good understanding of the total color variability in wood, how to segment the total variability into representative classes, and how changing light standards can affect the performance of the system.



(a) (b) (c) (d)

Figure 6. —*Grain pattern samples for (a) flat grain, (b) course grain, (c) fine grain, and (d) cathedral grain.*

A preliminary study was performed to test the accuracy of grain sorting on red oak parts. Ten grain pattern samples were selected from each of 4 different grain classes: flat grain, course grain, fine grain, and cathedral grain (Fig. 6). All samples were used to train the grain pattern recognition system. The same samples were used to test the accuracy of the trained system. An overall accuracy of 70 percent was found in classifying the samples into the correct grain class. The highest accuracy was found in classifying flat grain (90%), and the lowest accuracy was found in distinguishing between fine and course grain patterns (60%). Grain pattern matching is extremely difficult in parts where 2 or more grain patterns can be observed in the same part. While this preliminary grain pattern matching test was encouraging, further research is needed to characterize and quantify the characteristics of grain pattern that is desirable for a particular application.

Current Status

The commercial version of the color sorting system was developed by NOVA Technologies in Charlotte, North Carolina. Parts are fed into the system from right to left at speeds of 2 ft./sec. (61 cm/s). This application used 11 red oak color classes to represent the variability in panel part color. The system inspects both faces of a part, sorts it into a color class, and uses a printing device to code the part for color class and best face. As an alternative to printing a code, the system can drive an automatic part sorting system. Based on a P90 Pentium processing computer, a minimum spacing of 4 in. (11 cm) between parts is needed to allow the system to process both faces of a part and determine its color class.

The color sorting system has demonstrated reasonable service maintenance requirements and has been well received by plant personnel. Extensive plant testing has led to enhanced commercial software to better characterize the large color variations present in red-oak panel parts including those variations due to small knots and mineral streaks. Also, the continual increase and speed and decrease in cost of PCs has led to the incorporation of a number of improvements in the real-time operation software and hardware. Commercial versions of the system are currently being marketed under the name CESYS (Color Evaluation SYStem) by Group Seven Systems in Hudson, North Carolina.

Summary

This paper describes a color and grain sorting system for use in sorting edge-glued panel parts. Operational in-plant tests indicate that the system performs very well for color sorting red oak panel parts. The system can be trained for other wood species as well. The introduction of the system into the plant environment exceeded production goals and was well received by plant employees. A commercial system has been developed by NOVA Technologies and is currently being marketed under the name of CESYS by Group Seven Systems.

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